Chapter 13
Integrating Generative AI and Digital Twin Technologies for Smart Fabrication and Autonomous Manufacturing Workflows

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ABSTRACT

The study presents a novel concept for Smart Fabrication and Autonomous Manufacturing Work-flows based on the convergence of Generative AI models and the Digital Twin paradigm. The aim is the prediction and optimization of the most significant machining parameters such as surface roughness, tool life, and energy consumption using advanced AI models and simulation of real-time machining with

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a responsive digital twin. 50 work-pieces' tool wear, surface finish, and energy consumption data were obtained. Four generative AI models VAE, GAN, Reinforcement Learning (RL), and CAM Code Transformer were trained and evaluated with respect to the RMSE, MAE, R^2, and MAPE criteria. The RL model exhibited the highest accuracy and served as the digital twin input engine. The twin simulated machining operations dynamically with rein-forcement learning and allowed for proactive adjustment for performance enhancement. Compara-tive analysis revealed high correlation of predicted and measured values. Optimization using AI and digital twin improved tool life and efficiency

INTRODUCTION

The swift progress of Industry 4.0 has revolutionized conventional manufacturing into highly automated and smart systems, fueled by digital technologies like Artificial Intelligence (AI), the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Digital Twins (Assuad, Leirmo, & Martinsen, 2022; Pal et al., 2025; Wang et al., 2022). In this changing scenario, the use of Generative AI and digital twin technology is also attracting considerable attention for its ability to streamline production, improve decision-making, and facilitate self-learning features in the manufacturing sector. Generative AI models, which can create new data patterns from distributions learned, are being used to a greater extent to simulate, predict, and optimize intricate industrial processes. Generative AI models can offer real-time insights and predictive feedback to help dynamically adjust machining parameters to minimize defects, reduce waste, and enhance efficiency overall (Siddiqi et al., 2025; Sharma & Gupta, 2024).

Some research studies have investigated the use of machine learning and deep learning models for manufacturing operations, especially to forecast important parameters such as surface roughness, tool wear, and energy usage. Artificial Neural Networks (ANN), Support Vector Machines (SVM), Decision Trees, and Random Forests are some of the models employed for predicting machining performance from real-time sensor inputs. Although these methods have achieved encouraging performance in static prediction tasks, they are not very adaptable in dynamic settings (Singh et al., 2025; Min et al., 2019). Reinforcement Learning (RL), however, has proven to be a highly effective method for learning real-time control and decision-making. Its capacity for learning optimal policies directly from interaction with the environment makes it viable for application to autonomous manufacturing where continuous learning and adaptability are paramount (Sultanpure et al., 2024; Ariansyah et al., 2023).

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